● PRINTER RUSH ●
(PTO ASSISTANCE)

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[RUSH] **MESSAGE:**

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MD

[XRUSH] **RESPONSE:**

INITIALS:

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REV 10/04

other dental cleaning

teeth, dentures, gums, [redacted]ther prosthesis or restorations, denta[redacted]ng material, dental adhesives or the like or other dental objects as well as any other objects or materials as the "object," "material," "surface," etc.

These and other objects, advantages and features of the invention will be more readily understood and appreciated by reference to the detailed description of the preferred embodiments and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a side view of the intensity of light projected from a fiber optic illumination source of the prior art;

Fig. 2 is a side view of non-uniform illumination from a fiber optic illumination source of the prior art;

Fig. 3 is a side view of non-uniform illumination from a bifurcated fiber optic illumination source of the prior art;

Fig. 4 is a perspective view of an RGB sensor of a prior art intraoral camera collecting color data from a tooth;

Fig. 5 is a side view of a the generic searchlight illuminator of the present invention;

Fig. 6 is an exploded perspective view of an optical measurement instrument;

Fig. 7 is a side view of a region of constant irradiance;

Fig. 8 is a side view of a modified region of constant irradiance used in searchlight illumination;

Fig. 9 is a graph comparing illumination intensity of various light sources as relative distance to an object is varied;

Fig. 10 is a sectional view of a preferred illuminator;

Fig. 11 is an exploded perspective view of an imaging subsystem;

Fig. 12 is a flow chart of an alignment process of the imaging subsystem;

Fig. 13 is [illegible]nd view of a sanitary shield;

Fig. 14 is a side elevation view of the sanitary shield in use;

Fig. 15 is a side view of a line of sight feature of the optical measurement instrument;

Fig. 16 is a perspective view of the line of sight feature;

Fig.17 is a perspective of a sealed window of the optical measurement instrument; and

Fig. 18 is a perspective view of the optical measurement instrument in a docking station.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to Fig. 6, the preferred embodiment of the optical measurement instrument 10 will now be described. The optical measurement instrument 10 generally includes a housing 12, display 18, processor 20, imaging subsystem 50, illuminator 80, power source 90, and sanitary shield 300. The housing 12 includes subparts 12a and 12b to allow easy assembly and access to the internal components housed therein. The housing subparts seat and seal together to create a housing that prevents contamination of sensitive internal components by dust and chemicals. The housing 12 may be constructed of any material; however, a light, easily cleanable, synthetic material, such as plastic, is preferred for handheld use and shock resistance.

The display 18 and the processor 20 may be separate or integrated as a unit as depicted. The display 18 is preferably a liquid crystal display (LCD). The LCD preferably has a touch screen interface to provide image control, data display and targeting feedback through a video viewfinder. As will be appreciated, any other display screens may be used. Alternatively, the optical measuring instrument may be connected via a cable (not shown) to a monitor or display (not shown) that is separate from the instrument for displaying images collected by the instrument.

In the preferred embodiment, the processor 20 is in electrical communication with the display 18, illumination assembly 80, and imaging subsystem 50. This processor is capable of processing digitized data collected from the imaging subsystem 50 and formatting it so that an image of that digitized data is output to the display screen 18. The processor preferably formats digitized measurements such as tristimulus value bandwidths collected by the image sensor 56 to form an image of the object measured on the display 18.

The processor 20 includes port 22 to connect to the instrument 10 to docking station, described in further detail below, to download images and/or data collected by the optical measuring instrument to a computer connected to the docking station for further analysis. Port 22 is also in electrical communication (not shown) with power source 90 so that the power source may be recharged when the instrument 10 is in its docking station.

Illuminator 80 is preferably mounted in the housing 12 in fixed relation to the imaging subsystem 50. This is accomplished via connectors 82 that may be of any configuration to hold the two assemblies in fixed relation. The fixed relation is preferably configured so that the illuminator 80 illuminates an object, such as a tooth, with light at a selected angle and the light reflected from the tooth is collected by the imaging subsystem 50 at a selected angle. In a preferred embodiment, the illuminator illuminates an object in an angle 18 degrees off normal and the imaging subsystem 50 collects light reflected from the object at an orientation normal to the object's surface. This configuration helps to reduce glare artifacts.

Of course, the illuminator 80 and imaging subsystem 50 may be configured in any angular configuration depending on the desired application. For example, the illumination and image capturing may be done both normal to the tooth. As will be also appreciated, the relation between the illuminator assembly 80 and imaging subsystem 50 may be configured such that with a combination of a beam splitter as known in the art,

captur of be

illumination and ~~capturi~~ [redacted] light reflected from an object may ~~be~~ [redacted] done normal to an object's surface.

As will be appreciated, other conventional illumination assemblies may be substituted in the optical measurement instrument as the application requires. The assemblies may also include polarizers that limit the effect of specular gloss in the captured image.

<u>Searchlight Illumination</u>

The preferred embodiment of the optical measuring instrument uses searchlight illumination to illuminate objects during optical characteristic measurements. As used herein, "optical characteristics" means characteristics such as color, shade, translucence, gloss and/or shape. "Searchlight illumination" means illumination wherein the object measured is illuminated with constant irradiance. This definition is more readily understood with reference to Figs. 7 and 8. Fig. 7 illustrates the constant irradiance phenomenon explained by J. Scheuch in his article, *Modeling of Constant Irradiance Illumination System*, pp. 22-27, SPIE Vol. 3428 (1998), hereby incorporated by reference.

As explained, Fig. 7 depicts a collimated uniform light source 600. The diameter of the integrating sphere exit port 620 is referred to as $Ø_S$, while $Ø_L$ refers to the diameter of the collimating optic 628, here, a thin lens. The effective focal length of the optic is referred to as f. Any point on the exit port of the integrating sphere 620 will produce a flux of collimated rays 640a and 630a to the right of the lens 628. The original light flux 630 and 640, formed by the top and bottom edges of the exit port 620 are shown. The shaded triangle 650 to the right of the lens 628 represents the region, or cone, of uniform irradiance. Although depicted as a two dimensional triangle, it will be appreciated that the region is actually a three-dimensional cone. Of course, depending on the aperture 620 and lens 628, the region of constant irradiance may take on cones of different shape as desired. At any point within this region 650, normal to the optical axis 645, irradiance will be a constant value. At points outside of the cone, the irradiance will fall off as the distance from the cone

paraxial distance .... cell - 15

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increases. The ~~paraxial~~ [redacted] ~~ance~~ from the lens to the tip of the [redacted]s referred to as the critical distance Z_c and is given by:

$$Z_c = \frac{f\varnothing_L}{\varnothing_S} \qquad (2)$$

At any point z along the optical axis where $z<z_c$, the diameter of the uniform field $\varnothing_F$ can be approximated by:

$$\varnothing_F = \frac{(z_c - z)\,\varnothing_L}{z_c} \qquad (3)$$

The region of uniform irradiance can be extended in length along the optical axis 745 as illustrated in Fig. 8. By positioning the exit port 720 at the focal of the achromatic doublet lens 738, the region of uniform irradiance 760 may be extended a substantial distance along the optical axis 745, as discussed in further detail below.

The advantage of searchlight illumination over conventional illumination techniques is illustrated in the graph of Fig. 9, entitled "Illumination Intensity of Various Light Sources as Distance is Varied." This graph illustrates the illumination intensity along the central axis from (a) a theoretical point source illumination 706, (b) conventional fiber optic illuminator 704, and (c) a searchlight source 702 used in the preferred embodiment. In the graph, the Y axis represents light intensity along a central axis of the illumination sources projecting in the same inaction as the light is projected. The X axis represents the relative distance from the target, that is, the object measured, to each source.

As shown, the intensity along the central axis from thc theoretical point source 706 and fiber optic illuminator 704 is very strong when the target is near these sources; but that intensity rapidly decreases as the relative distance from the source to the target increases. In contrast, with a searchlight illuminator 702, which, by definition, has constant irradiance, the intensity along the optical axis remains substantially uniform at a distance within the operating range of the illuminator, as depicted by example here, from a relative distance of about 0.95 to about 1.0. At a distance somewhat greater than 1.05, the intensity from the

begins than

searchlight gradually begins to decrease; but at a rate much less than the theoretical point source 706 and the conventional fiber optic illuminator 704.

Of course, as the illumination source distance to target is significantly increased (not shown on graph), even the searchlight illumination intensity will begin to decrease along the optical axis. But, for purposes of the carrying out the preferred embodiment of the present invention, illuminated targets or objects are positioned at a pre-selected distance from the searchlight source so that they are substantially within the region of constant irradiance.

The graph of Fig. 9 and related data are exemplary only; targets placed at different relative distances from the light sources may be illuminated by the searchlight source differently than as depicted. Moreover, even though the illumination intensity apparently decreases for searchlight sources along a central axis at relative distances greater than about "l," an object disposed at relative distances greater than 1 still may be considered to be illuminated within the region of constant irradiance. As used herein with reference to the present invention, "constant irradiance" means irradiance (or light) that is substantially uniform in intensity in three dimensions; the X and Y dimensions, and the Z dimension, which is preferably axially aligned with the central axis of a source of light. As used herein with reference to the present invention, "substantially uniform" means that the light preferably varies about ± 4% in any of the three dimensions, more preferably about ± 2% in any of the three dimensions, and most preferably about ± 1% in any of the three dimensions.

The optical measuring instrument of the preferred embodiment uses searchlight illumination to illuminate an object while the object's optical characteristics are measured. Fig. 5 generally depicts a searchlight illuminator and Fig. 10 depicts the searchlight illuminator as it is configured in the preferred embodiment of the optical measurement instrument.

reference ... and projected

With ~~refe~~[redacted]ce to Fig. 5, light fluxes 530 and 540 [redacted]~~rojected~~ through exit port 520 of illumination source 518 which is depicted as an integrating sphere, but may be any uniform diffuse source. The light fluxes are projected onto lens 528 positioned at a pre-selected distance M from the illumination source 518. Depending on the desired size of the region of constant irradiance 560, this distance M is experimentally determined. The light fluxes 530 and 540 transmitted through lens 528 form a region of constant irradiance 560 including transmitted light fluxes 530a and 540a. The lens may, of course, be of any configuration capable of forming regions of constant irradiance and need not be limited to the achromatic doublet lens depicted.

The searchlight illuminator 80, including source 518 and lens 528, preferably is placed a pre-selected distance D from the center of the object for which optical measurements are to be collected. The center of the nominal object or target may be placed at about 50 millimeters to about 100 millimeters from the lens, preferably from about 60 millimeters to about 70 millimeters from the lens, more preferably from about 63 millimeters to about 67 millimeters from the lens, and most preferably, about 65 millimeters from the lens. This distance D establishes a reference distance within which all points of the object optically measured are illuminated in the region of constant irradiance 560. For purposes of taking optical measurements of teeth, it is preferable to illuminate a substantial portion of the tooth or remaining teeth with the region of constant irradiance 560.

To establish distance D and insure that the points of the object measured are within the region of constant irradiance, a spacer is used to separate the illuminator 80 from the tooth. Preferably, a sanitary shield, described in further detail below, is attached to the optical measuring instrument that includes illuminator so that when the shield is disposed against or adjacent to the tooth, the distance D is established and the tooth is positioned in the region of constant irradiance. As will be appreciated, the illuminator 80 is positioned so that

illuminator predetermined

1126 The ~~illuminator~~ housing holds lens 828 a ~~predetermined~~ distance from light source 818 to optimize the searchlight illumination projected from the illuminator 80. Of course, as discussed above in reference to Fig. 5, the distance from the lens to the light source may be varied to obtain the desired searchlight illumination. The lens preferably is an achromatic doublet lens, but as will be appreciated, any lens capable of providing a region of constant irradiance at significant distances along the optical axis of the lens may be used.

With reference to Fig. 6, the illuminator 80 is configured in fixed relation to the optical imaging subsystem 50 so that the illumination reflected from the object measured is reflected back to the imaging subsystem 50 for sensing and subsequent measurement of optical characteristics of an object. In operation, the illuminator depicted in Fig. 10 performs in the same manner discussed above in reference to the generic illuminator of the present invention depicted in Fig. 5.

Imaging Subsystem

With reference to Figs. 6 and 11 in the imaging subsystem 50 will now be described. The imaging subsystem is in electrical communication with the processor 22 to enable transfer of optical characteristic data in digitized form collected by the imaging subsystem 50 to the processor 20. The electric prongs 52 may be connected to a cable (not shown) that provides this electrical communication with the processor 20. Additionally, the connector 52 may be connected to an additional cable (not shown) that provides electrical communication with the power source 90 to enable the operation of motor 54 and image sensor 56 depicted in Fig. 11.

With particular reference to Fig. 11, the preferred imaging subsystem includes lens 58 mounted in cover 59; filter wheel assembly 60 rotatably mounted to and driven by stepper motor 54 which is mounted to support plate 66; position sensor 62 for indexing rotation of the filter wheel 60, and image sensor 56. The subsystem may optionally include an infrared blocking lens 64 to prevent infrared bandwidths from reaching the image sensor.

enlarged tooth 15

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All of these elements ar[redacted]gned so that light L, reflected from a ~~too~~[redacted]~~s transmitted~~ through lens 58, one of the filter elements 60a-f, and the infrared blocker 64, ultimately impinges on and is captured or collected by the image sensor 56. The image sensor 56 converts this light L to digitized form and transfers the digitized form to processor 20.

Alternatively, the imaging subsystem may be configured so that the filter assembly is positioned between an illumination source and the object measured (not shown). In this manner, light from the illumination source would be transmitted through the filter assembly elements before being reflected from the tooth; however, reflected light impinging on the image sensor would still be of bandwidths selectively transmitted by the filter elements.

The lens 58 preferably has low chromatic aberration over the visible light spectrum from the 380nm to 700 nm wavelength range. The lens focuses light L toward the image sensor 56, and causes the light to be transmitted through the elements of the filter wheel 60a-60f in the process. The filter wheel assembly of the preferred embodiment is a sector of 180 degrees including six elements. Of course, the assembly may be of any shape and include any number of filter elements.

The filter wheel assembly 60 of the preferred embodiment includes filter elements 60a-f, wherein filter elements 60a-d are of pre-selected band pass functions. "Band pass function" means information that is used to specify how a filter absorbs specific wavelengths of light as that light, also referred to as "radiant flux," is transmitted through a material. More preferably, filter element 60a has a band pass function that permits it to transmit only X tristimulus value bandwidths and attenuate all other bandwidths; 60b has a band pass function that permits it to transmit only Y tristimulus value bandwidths and attenuate all other bandwidths; 60c has a band pass function that permits it to transmit only Z tristimulus value bandwidths and attenuate all other bandwidths; and 60d has a band pass function that permits it to transmit only X' tristimulus value bandwidths and attenuate all

These bandwidths

other bandwidths. These filters consistently attenuate ~~bandwidths~~ outside selected bandwidths to less than about 1/40th, preferably less than about 1/100th, and more preferably less than about 1/1000th of the value of the maximum transmittance of the filter. Of course, the filter elements 60a-d may have any band pass function and attenuation as desired, and they may be altered in number so that only a selected number of filters are used in measurement.

Optionally, the filter assembly 60 may include opaque element 60e to establish dark current information of the image sensor 56. Dark current information is current that flows in an image sensor when no optical radiation is impinging on the sensor. This current effectively distorts the electronic signals transmitted by the sensor to the processor. Accordingly, it is preferred to measure this dark current information and subtract it from the electronic signals generated during collection of bandwidths transmitted to the sensor so that subsequent optical characteristic measurements do not include this dark current information. The filter wheel may also include an open element space 60f that transmits all light wavelengths to the image sensor. Transmitting all light wavelengths to the image sensor may be desired when initially acquiring an image of an object to help identify regions of the tooth that have high gloss.

With reference to Fig. 11, the filter is indexed with index 69 that interacts with position sensor 62 to synchronize the timing of imaging sensing by image sensor 56 and alignment of individual filter elements 60a-f over the image sensor 56. The position sensor may be a photodiode position sensor or any other sensor capable of sensing movement of the filter wheel 60 via detection of the position of index 69. The position sensor 62 is in electrical communication with the processor 20 so that the processor may initiate the stepper motor 54. Stepper motor 54 sequentially rotates the filter wheel assembly in pre-selected angular increments to position elements of the filter wheel 60a-60f over the image sensor so that light is transmitted through the light transmitting elements to the image sensor 56.

stepped the

The stepp[illegible] motor 54 is mounted to the back of th[illegible] support plate 66 in a manner that limits contamination, magnetic field interaction, and heat transfer from the motor to the image sensor 56. The stepper motor preferably rotates the sectored filter wheel 60 in an indexed versus free-spinning manner.

The image sensor 56 is preferably a complimentary metal-oxide semiconductor (CMOS). As will be appreciated, any monochromatic sensor or photo detector may be substituted for the CMOS, including but not limited to a charged coupling instrument (CCD) sensor. As will be appreciated, the image sensor collects or captures bandwidths of the light L that is transmitted through respective filter elements 60a-d, converts those functions to digitized form, and transfers the digitized form, also referred to as electronic signals, to the processor 20.

The stepper motor 54 and image sensor 56 are all synchronized, preferably by the processor 20, so that the image sensor 56 collects the bandwidths transmitted through each filter element 60a-d when those filters are aligned one by one over the image sensor 56. The position sensor provides feedback via interaction with index 69 to the processor 20 to initialize and deactivate the stepper motor 54 in a desired manner.

With reference to Fig. 11, the preferred operation of the imaging subsystem will now be described. Light reflected from an object, preferably a tooth, travels pathway L through lens 58. Lens 58 focuses light reflected from the tooth toward the image sensor 56. In so doing, selected bandwidths of the light L is transmitted through one of the filter wheel elements 60a-f. Each transmission of light L through an individual filter, and each instance where no light is transmitted through the opaque element, and each instance when all light is transmitted through the open element is referred to as a "frame." The stepper motor 54 sequentially aligns each of the filter elements 60a-60d and optionally the opaque and open filter elements 60e and 60f, respectively, over the image sensor 56. The image sensor 56 collects a frame when each filter element is placed over the sensors. Accordingly, in the

preferred embodiment, the image sensor 56 collects, frame by frame, different tristimulus value bandwidths that are transmitted through the elements of the filter wheel 60.

The alignment of elements 60a-f is controlled by stepper motor 54 which is controlled by processor 20. In the preferred embodiment, when color measurement of light L reflected from a tooth is initialized, the stepper motor is in a "park" mode; that is, index 69 is aligned with position sensor 62. During measurement, the processor directs the stepper motor to rotate from the park mode through a plurality of partial movements consequently turning the filter wheel assembly 60 a plurality of pre-selected angles. These angles are such that each filter wheel element 60a-60f is positioned over the image sensor so that image sensor 56 collects a frame of data for light transmitted through each of the filter elements individually or for dark current into motion when element 60e is positioned over the sensor. In this manner, only one bandwidth is transmitted to and captured by the image sensor at a given time or in a single frame.

In the preferred embodiment, the image sensor 56 takes three color measurements of a tooth. Each measurement comprises nine frames of data, which are subsequently stored in a processor 20 and combined to form a single measurement, or "image" of the tooth. Those frames represent two transmissions of X bandwidths of light L through filter 60a two transmissions of Y bandwidths of light L through filter 60b two transmissions of Z bandwidths of light L through filter 60c, two transmissions of X' bandwidths of light L through filter 60d, and a single dark current information frame when the opaque element 60e is positioned over the image sensor 56. This duplication of frames helps to integrate over time the collected bandwidths and may provide data needed for stabilization of the image.

As used herein, "stabilization" means combining the frames of data collected at different points in time so that the resultant image does not indicate that the optical measuring instrument was moved between the points in time during which the frames were

MOVEMENT 15

degraded, then column ~~movement~~ is undone. An error function is calculated that assesses angular misalignment in step 1024. In step 1026, correlation is assessed. If correlation has degraded, then the rotation is undone.

In step 1028, a query is offered; has the loop been met? If yes, the process skips to macro step 2, and 1030, where it returns to final correlation value loop count, loop count, row offset, column offset and angular rotation values. The process proceeds to being done 1032. In step 1028, if the response is no, a inter-image correlation value is computed 1034; and the process skips to macro step 1 again to repeat all steps as necessary any number of times so that the process proceeds to done 1032. Of course, the preferred process may be modified in sequence. Steps may be modified and/or selectively repeated. Different steps may be added as well, depending on the desired application.

When the points of each frame are aligned with all the points of all other frames, the frames are collectively displayed to form an image of the object that reflected the light collected by the sensor. Preferably, a substantial number, if not all, of the points of this image will include all the tristimulus value bandwidths, that is the X, Y, Z and X' tristimulus bandwidths that were collected by the image sensor. This image is preferably displayed on display 18 and stored in microprocessor 20. The image may be downloaded from the microprocessor 20 to a personal computer. In embodiments where only tristimulus bandwidths are collected by the imaging system, it will be appreciated that therc is no need to perform lengthy calculations to derive tristimulus values if the output of the system be in tristimulus value format.

As will be further appreciated, the bandwidths collected by the image sensor may be combined and averaged in an image of the object into regions of uniform bandwidths. It is also possible to arithmetically combine into color zones those adjacent image points where color deviation between these adjacent image points do not exceed a predetermined value. In this way, measured tooth color can be subdivided into several color zones having

bandwidths color zones

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different colors or bandwidths. The maximum number of such ~~color zones~~ in a prosthesis may be limited because a dentist or restoration manufacturer usually subdivides a prosthesis only into a limited number of color zones.

In addition to matching points to stabilize and/or align the frames to form an image of the tooth, the processor may also detect measurement errors if frames have been improperly collected. For example, if the operator of the optical measurement instrument drastically rotates or moves up and down or side to side the measuring instrument while sequential frames are being collected, one or more of the collected frames may be drastically different from the other. For example, one frame may be of a tooth and the next may be of a gum due to the drastic movement of the optical measuring instrument between frames. Accordingly, it would be difficult to align the points of one frame with the corresponding points of other frames because the frames would be quite different.

In cases where the processor detects that the frames collected are sufficiently different from one another so that corresponding points of different frames cannot be matched to form an image of the tooth, the processor indicates to the operator that the measurement must be redone. This indication may be communicated via display means or any other conventional alarm means. Accordingly, the operator retakes the optical characteristic measurement of the tooth to collect satisfactory data. As a result, the optical measuring instrument insures accurate and complete images are collected for further processing and manufacture of dental prosthesis.

Additionally, the processor preferably has the capability to store three or more images of object. These images may be recombined or welded together using appropriate welding software to combine multiple images into a single image. For example, dentists may use welding software to arrange individual images downloaded from the optical measuring instrument into a single image that replicates the configuration of teeth surrounding a damaged tooth in a patient's mouth.

interior preferably

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The interior of the shield's hollow body is preferably opaque or otherwise colored with a dark material that prevents ambient light on the exterior of the shield from entering into the shield and polluting the data collected in the image field 350.

The shield 300 may also include indicia 340 disposed on first end 310. The indicia are preferably configured on end 310 so that it is included in the image field 350 when an image is collected. These indicia may be of any type, but preferably indicates the origin, such as manufacturer or distributor of the disposal shield to prevent counterfeiting thereof. The indicia 340 may also include patient information, a shield lot number, an expiration date, or any other information relevant to the patient or the optical measuring instrument. The indicia may be printed on, included in, affixed to or otherwise associated with the shield in any conventional manner. For example, the indicia may be a printed adhesive label or a barcode.

In the preferred embodiment, the shield establishes a predetermined distance to an object from an illumination source 80 or image sensor 56 as depicted in Fig. 14. The length of the shield L is pre-selected so that when aperture 312 is disposed adjacent to or in contact with the object to be measured, for example the tooth T, the illumination source 80 and image sensor 56 is a specific distance D from the object T. Accordingly, the precise illumination or sensing by the illuminator 80 or sensor 56 may be duplicated in every measurement. This specific distance is also pre-selected to prevent diffusion or scattering of the light generated by the illumination source 80 by the time the light reaches the aperture or object measured.

The shield 300 may be secured to the optical measuring instrument as depicted in Fig. 17 in any convention manner. Preferably, the shield includes clips 324 that releasably clips to pegs 224 of the optical measuring instrument. Of course, the shield may be secured to the optical measuring instrument by any conventional fitting as the application requires.

with

As wi[illegible] appreciated, the shield may be of paper or plastic or other material which may be disposable, cleanable, reusable or the like in order to address any contamination concerns that may exist in a particular application. The shield may also be disposable or reusable. In the case of reusable shields, the shield is preferably constructed of material that can withstand sterilization in a typical autoclave, hot steam, chemiclave or sterilizing system.

Line of Sight Viewing

Figs. 15 and 16 illustrate the line of sight viewing of the preferred embodiment. The optical measuring instrument 10 includes housing 12 and display 18 mounted therein. As explained above, an image sensor is also included in the housing 12. The image sensor collects images from an image sensor view 402, also referred to as "line of sensing." The line of sensing projects outward from the housing 12, through the installed shield 300 toward the object for which an image is to be collected, for example the tooth 4. The object should be disposed in this line of sensing 402 so that the optical measurement instrument may sense and measure the optical characteristics of the object.

Once the image sensor takes a measurement of the object in the line of sensing 402, that measurement is processed by the processor of the instrument (see Fig. 6) and transferred to the LCD 18. The LCD displays the data as an image thereon in the preferred embodiment. The image may be magnified or reduced if desired. Of course, any conventional dynamic display may be used in place of a LCD.

With the image displayed on the display 18, an operator 6 may view the display along a line of viewing 400. This line of viewing 400 is aligned with the line of sensing 402 so that the operator 6 views the tooth on the display in the same perspective as the image sensor senses the tooth. Manipulation of the line of sensing 402 preferably corresponds to a different image being output on the display 18. For example, when an operator moves the device, and consequently the line of sensing 402, to the right of the tooth

the object

the

4, the image output on [redacted]screen 18 will correspond to whatever o[redacted]t is to the right of the tooth. More basically, a user may manipulate the device to realign the line of sensing by viewing an image on the screen without having to reverse or otherwise alter his normal thought process for acquiring and viewing an image.

With reference to Fig. 15, the display 18 is preferably aligned in parallel behind the image sensor 56 in housing 12. And preferably, the display 18 is generally perpendicular to the line of sensing 402 and/or line of viewing 400. Of course, the screen 18, sensor 56, line of sensing and line of viewing may be aligned in other configurations so the line of viewing 400 is axially aligned with the line of sensing 402.

The optical measurement instrument 10 is configured in any way that allows the operator to manipulate the instrument 10 and simultaneously view the same image that the sensor senses on a display on the instrument without periodically having to look away from the display and realign the image sensor's line of sensing. Accordingly, the operator may view the display alone along line of viewing 400 to precisely align the line of sensing 402 so that the instrument collects the image of the tooth as desired.

<u>Sealed Unit</u>

With reference to Figs. 16 and 17 the optical measurement instrument generally includes housing 12, divided into subparts 12a and 12b, display 18 and window 230. With particular reference to Fig. 17, the front portion of the housing 12 defines aperture 240 covered by window 230. The aperture allows illumination to be projected out from the interior of the housing 12 and allows light reflected from an object to enter back into the housing 12 and be sensed by an image sensor (not shown). The aperture 240 may be of a variety of configurations and sizes that facilitate illumination and sensing characteristics as desired.

The aperture is circumferentiated by an internal lip 210 that is preferably formed as part of the housing 12. Disposed over the lip is window or cover panel 230.

made material

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Preferably, this cover is [redacted] from plastic, glass or other synthetic [redacted] that allows high efficiency transmission of light through it. Disposed between the lip 210 and the window 230 is seal 220. The seal may be any gasket or seal, for example a sealing adhesive, that prevents "pollutants"--meaning dust, dirt, debris, moisture, cleaning agents, and chemicals--from entering the interior of the housing body 12 through or around the aperture 240.

The display 18 is preferably sealed to or into the housing 12 in a manner that prevents pollutants from entering the interior as well. It is preferred that the display is touch sensitive and is able to provide a means to control and operate the device. In this manner, no difficult to clean around external buttons are included in the housing.

Subparts 12a and 12b are preferably seated together in a manner that also prevents pollutants from entering the interior of the housing body along the portions of the subparts where the subparts connect to or seat against one another.

As explained, all of the above elements, the sealed window 240, the mated subparts 12a, 12b, and the display 18, prevent pollutants from entering the interior of the device when the pollutants come in contact with the device, such as when the device is wiped down with cleaning or sterilizing agents, or when the device is dropped on a dirty floor. However, these elements do not significantly prevent the pollutants from entering the interior of the device if the device is fully submersed in pollutants, for example, if the device is submersed in liquid cleaning agents.

The device of the present invention in some embodiments may include a port 22 or other connection for communication with a docking station (Fig. 18), computing device and/or power source (not shown). Typically, it is difficult to seal this port to prevent pollutants from entering the interior of the housing 12.

The optical measurement instrument is easily sanitized and/or sterilized. Users may clean it by wiping it down without significant worry of leaking sanitizing or sterilizing agents or other cleaning agents into the interior of the housing 12, a consequence

damage instrument

that potentially might damage the internal components of the instrument. Of course, care must be taken to prevent excessive exposure of a connection or port to pollutants to prevent those pollutants from entering the interior of the device. In periods of non-use, or use in dusty regions, the risk of dust or debris entering the housing is significantly decreased.

Dental Prosthesis Manufacture

The preferred process of creating a dental restoration or prosthesis from optical measurements taken from a damaged tooth or surrounding teeth will now be described. To begin, a dentist uses the preferred optical measuring instrument to measure the optical characteristics of a tooth or teeth that surround an area that was previously occupied by a tooth. These optical measurements are converted to an image or plurality of images in the optical measurement instrument. The images may be downloaded from the optical measurement instrument to a computer where they may be stored. Of course, the image may be stored in any appropriate electronic file format. Once the image is stored in the computer, it forms what is referred to as a restoration file. From this restoration file, the measured optical characteristics may be mathematically manipulated by the computer to be viewed as an average characteristic map, as a grid of individual characteristics, as a contoured characteristic map, or any other desirable format as will be appreciated by those skilled in the art.

Next, the dentist transmits the restoration file to a restorative prosthesis-manufacturing laboratory with any acceptable means. Preferably, however, the file is forwarded using electronic network correspondence.

At the lab, a technician downloads the restoration file to reconstruct the patient's mouth, and in particular, the new prosthetic replacement for the damaged or missing tooth. Software capable of this reconstruction is available from X-Rite, Incorporated of Grandville, Michigan. After the technician creates the restorative prosthesis, an image of the prosthesis, preferably with the optical measuring instrument of the preferred embodiment.

INSERT Image

The i[redacted] of the prosthesis is inserted into an [redacted]~~image~~ of patient's mouth derived from the restoration file to determine quality and accuracy of the restoration. This may be done in several ways. First, the technician may use her own optical measuring instrument to take measurements of the prosthesis to create an image of the prosthesis also referred to as "prosthesis data." She then takes this image and inserts it into an image of the patient's mouth taken from the restoration file. Of course, the technician may also compare the prosthesis data to the image of the original tooth, if one exits. The technician conducts a comparison of the image of the tooth to the image of the patient's mouth or damaged tooth before the restoration is shipped from the lab. The technician may then determine the quality and accuracy of the restoration and decide whether or not to ship it to the dentist for installation in the patient's mouth.

In a second alternative embodiment, the technician may use the optical measuring instrument to take measurements of the prosthetic restoration to create an image of the prosthesis and send that image to the dentist. The dentist may then visually insert the new tooth image into an existing image of the patient's mouth to determine the quality and accuracy of the restoration. Based on his or her own judgment, the dentist may then contact the lab to confirm or decline the restoration. In cases where the restoration is confirmed, the lab will ship the restoration to the dentist for installation in the patient's mouth. In cases where the dentist declines the restoration because it is not an acceptable match, the lab constructs another restoration and takes a new image of that restoration. The new image is forwarded to the dentist to compare that new image to the image of the damaged tooth. This process may be repeated until an accurate restoration is created.

In a third alternative embodiment, the technician may simply create the prosthesis and send it to the dentist. The dentist uses her own optical measurement instrument to obtain an image of the prosthesis. That prosthesis data is visually inserted into an image of the patient's mouth or compared to an image of the damaged tooth to determine

accuracy of acceptable

the quality and ~~accuracy of~~ the restoration. If the restoration is acceptable, the dentist will install it in the patient's mouth. If the restoration is unacceptable, the dentist may request the lab to create another restoration or alter the restoration in a manner to make it an accurate duplicate of the original tooth for which it was designed to replace.

Docking Station

With reference to Fig. 18, the optical measurement instrument 10 docks or rests in docking station 14 when not in use or when downloading images from the instrument 10 to a computer (not shown) connected to the docking station for further analysis of these images or to forward those images to a third party. The docking station 14 includes support 15 to hold the instrument 10 in a ready-to-grasp position. The instrument also rests in port 24 that includes a plug (not shown) to interface with portal 22 (see Fig. 6) for download of images and recharging of power source 90 of the instrument 10. The docking station may also provide a data connection for download/upload of patient information and/or download/upload of image and modified patient information to/from the instrument 10. Of course any other information as desired may be downloaded/uploaded.

In an alternative embodiment, the instrument may include a transmitter and/or receiver so that it can communicate with another instrument, with a docking station and/or directly with a computing device using a wireless connection wherein data may be transported through radio frequencies, light modulations, or other remote wireless communication means.

The above descriptions are those of the preferred embodiments of the invention. Various alterations and changes can be made without departing from the spirit and broader aspects of the invention as defined in the appended claims, which are to be interpreted in accordance with the principles of patent law including the doctrine of equivalents. Any references to claim elements in the singular, for example, using the articles "a," "an," "the," or "said," is not to be construed as limiting the element to the singular.